

Implementing a STEM English Course for Undergraduate Students

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This paper describes the course content created for the STEM English course in the English Language Program (ELP) at Kanazawa Institute of Technology (KIT). The course was developed with the aim of enhancing student's English language skills in the fields of science, technology, engineering and mathematics (STEM) by implementing a hands-on, content and language-integrated learning (CLIL) approach. This course has been offered as one of the ELP courses available to students during the second semester. The results from a preliminary survey on students' perceived improvements on vocabulary development during the STEM English course have been positive. The results presented here indicate that both reading about the content topic and presenting results from hands-on experiments positively impact the student's perceived vocabulary development.

Keywords: STEM English, hands-on, authentic materials

1. Introduction

Students studying in science, technology, engineering and mathematics (STEM) fields have traditionally focused on specific skills and technical knowledge. However, recent trends in globalization have required colleges and universities to rethink how they prepare graduates for the workforce ¹⁾. The American Society for Engineering Education requested that, in addition to developing excellent technical capabilities, it is important that students also have the opportunity to develop soft skills in intercultural communication, team-work, higher-order thinking skills and various problem-solving approaches ²⁾. In Japan, STEM students face the additional task of improving their second language (L2) competency. The desire for Japanese STEM graduates with outstanding technical capabilities, as well as refined soft skills, is reflected in the Keidanren Japan Business Federation's overview of Basic Thinking on Education Reform (2016)³⁾. The report highlighted that to meet the rapid change in social and industrial structures represented by the "fourth industrial revolution" and Society 5.0, the next generation of science and engineering graduates will need broader educational backgrounds as well as abilities to communicate in foreign languages and collaborate with others to complete projects. Additionally, in 2018 the Ministry of Education, Culture, Sports, Science and Technology (MEXT) released the Basic Policy on Promotion of Science, Technology and Innovation for Sustainable Development Goals (STI for SDGs), in which it identifies the importance of fostering human resources with the ability to connect science with politics and administration on an international scale⁴⁾.

To meet these needs, this paper introduces an English course developed in the context of content and language integrated learning (CLIL) where L2 is used as the language for course instruction

and the language learning objectives are achieved through hands-on STEM content and activities.

The CLIL educational approach has widely been recognized as an effective framework for improving students' foreign language acquisition skills and social and critical thinking skills ^{5,6)}. Combining STEM content with the CLIL pedagogical approach has the potential to provide students with a productive environment in which their L2 communication and higher-order thinking skills can be fostered at undergraduate levels. CLIL is a dual-focused approach in which students learn content while at the same time practice using the target language ⁷⁾.

This paper will describe the structure and content of the 15-week STEM English course as well as its implementation. Survey data collected from students related to their perceptions of how the STEM English course impacted their vocabulary skills will also be presented.

2. The STEM English Course

The STEM English course is offered to all undergraduate students as part of the ELP second-semester course curriculum. The course is listed as an intermediate English class. It aims to attract first and second-year students who have completed the English Topics 5 (ET 5) course during their first semester at KIT. The STEM English course covers five fundamental concepts which include i) Unit 1: STEM Fundamentals ii) Unit 2: The Scientific Method, iii) Unit 3: The Bernoulli Equation, iv) Unit 4: Projectile Motion and v) Unit 5: Global Water.

2.1 Course Structure

The five topics mentioned above constitute the five units of the STEM English course. The five units are divided into two- or three-class sections, where one class equals a 100-minute class held once a week. The first unit, Unit 1: STEM Fundamentals, covers two weeks and Units 2 through 5 are covered in three-week blocks. Table 1 outlines the five units of the STEM English course and the amount of class time spent on each unit. With the exception of Unit 1, Units 2 through 5 follow the same lesson plan schedule pattern, that being i) lesson 1- topic introduction and reading comprehension, ii) lesson 2 - conduct an in-class experiment, and iii) lesson 3 - report and present experiment results.

Table 1 List of STEM English Units

Unit	Topic	Number of 100min classes
1	STEM Fundamentals	2
2	The Scientific Method	3
3	The Bernoulli Equation	3
4	Projectile Motion	3
5	Global Water	3

The fifteenth and final lesson of the STEM English syllabus is set aside as an integrated learning class. During this class, students engage in other English activities not directly related to STEM English, receive their final grade, and complete the KIT course evaluation surveys.

2.2 Course Content

The topic for each unit was selected to meet four main criteria. Firstly, each unit topic needed to cover a fundamental aspect of STEM that would allow students to engage with language and vocabulary that may be difficult to encounter in other English classes offered at KIT. Secondly, the unit topic needed to be general enough so that students from all majors offered at KIT would feel comfortable enrolling in the course. Third, it was necessary to create simple hands-on experiments that could be conducted within a 100-minute lesson, requiring few resources or tools to perform the experiments. Finally, the materials needed to provide the students with a meaningful and authentic context for language use, thus allowing students to develop their language skills while also learning the subject matter.

All five units have an English text the students must read. These texts were created by the author and written with the English level of the students in mind. A Flesch reading ease test⁸⁾ and a Flesch-Kincaid reading grade test⁹⁾ were conducted on the reading texts to verify the appropriateness of the text for the students. As a comparison, reading texts taken from the ET5 textbook, Reading Explorer 2¹⁰⁾, were also analyzed for reading ease and reading grade level.

Regarding the experiment content, the author conducted online research for suitable, short experiments for each unit and adapted them to suit the specific classroom environment.

2.2.1 Unit 1: STEM Fundamentals

In this unit there is no experiment or presentation component. Rather this unit focuses on introducing a wide range of fundamental STEM vocabulary and nomenclature common to many fields. This includes but is not limited to i) how to read large numbers in English, both numeric values and scientific notation, ii) how to read fractions and simple equations and iii) basic English grammar used when reading mathematics or scientific notation.

2.2.2 Unit 2: The Scientific Method

The scientific method unit was adapted from materials previously reported on by Wood (2019)¹¹⁾.

a. The Reading Text

The reading text was introduced during the first week of this unit. The text introduces students to the five steps of the scientific method. The five steps are 1) Ask a question, 2) Formulate a hypothesis, 3) Identify the variables and plan an experiment, 4) Conduct an experiment and analyze the data, and 5) Draw a conclusion. A reading comprehension and vocabulary exercise worksheet was also created. The objective of these tools was to have the students familiarize themselves with the key vocabulary and basic concepts of the scientific method.

b. The Hands-On Experiment

During the second week of this unit, students conducted an in-class experiment. The in-class experiments were designed to be simple enough for all students to be able to complete within a 100-minute lesson period using limited supplies and equipment yet challenging enough to ensure that students were engaged with the activity. The author devised ideas for five different experiments so that within one class, there were various activities with different input requirements leading to varied outputs. The five different questions were as follows:

- Does the height from which you drop a ball affect the height to which the ball bounces

back?

- Does a tall person have a long arm span?
- Does a tall person have a long step length?
- Does a paper plane fly further if its nose is folded back?
- Does a paper plane fly further if it has a wide wingspan?

Students work in groups of three to five (depending on class size) to complete the experiment activity. A separate worksheet was created for each question, as the requirements for planning the investigations and collecting the data differed for each case. However, all worksheets followed the same pattern of formulating a hypothesis (based on the question), identifying the variables, and planning and conducting the investigation, collecting and analyzing data, and drawing a conclusion. In addition to the worksheets, it was necessary to provide the students with scrap paper for making paper planes, tape measures (for measuring distance and height) and balls (table tennis balls and tennis balls).

c. Oral Presentation

The final component of this unit, conducted during the third lesson, required the students to summarize and explain the experiments they had conducted. For this activity, an oral presentation script template was provided to the students to help guide them through how to structure their presentations.

2.2.3 Unit 3: The Bernoulli Equation

The Bernoulli equation was chosen as it is a widely used, practical example of the law of energy conservation.

a. The Reading Text

The reading text for the Bernoulli equation was written to give the readers a brief understanding of who Daniel Bernoulli was and what he was doing that led to him having an equation named after him. The text also introduces the basic mathematical nomenclature used to express the Bernoulli equations and a short example of how the equation can be applied. The intention of this text was to provide students with a deeper contextual understanding of the scientist behind the equation.

b. The Hands-On Experiment

The experiment component for the Bernoulli equation unit required the students to apply Bernoulli's equation to calculate the pressure exerted inside of a water pistol when the water pistol is fired. A scaffolded worksheet was created to guide them through the activity. The experiment involves firing a water pistol at different pressures and measuring how far the water travels. The students are then able to relate the parameters at two different points (i.e. inside the water pistol and the muzzle of the water pistol) using the Bernoulli equation. In turn, this activity also demonstrates the law of conservation of energy. The materials and tools required for this activity include water pistols, tape measures, and chalk.

c. Oral Presentation

As with the scientific method outlined in section 2.2.2c, the oral presentation component of this activity required students to summarize and graph their results and explain the experiment and findings to the class.

2.2.4 Unit 4: Projectile Motion

Projectile motion was selected as a topic as it is a common phenomenon that most people are familiar with and, as mentioned above, a simple way to engage with STEM content in English. Understanding how projectiles travel through the air also requires a basic understanding of quadratic equations. In the author's opinion, providing students with an English environment where they can discuss and learn about topics such as quadratic equations is rare. There is the possibility that such content, or at least the fundamental ideas behind the content, may show up in the future careers of STEM graduates. Therefore, providing students with this opportunity seems valuable.

a. The Reading Text

The projectile motion reading text was written to show students how, throughout history, scientists have tried to understand and finally define how projectiles move through the air. A reading comprehension and vocabulary worksheet was also created to guide the students through the reading.

b. The Hands-On Experiment

The hands-on experiment for the projectile motion topic involves students creating a catapult from popsicle sticks, rubber bands, and plastic spoons. The catapults are then used to launch small projectiles, such as an eraser or a table tennis ball. Students are required to collect several parameters, such as the vertex and landing coordinates of their launched projectile. Using the vertex form of the quadratic equation, students calculate the equation for the parabola created by the catapult-projectile arrangement.

c. Oral Presentation

As mentioned above, the oral presentation component allows students to apply their English skills to explain how they went about their experiments and the implications of their results.

2.2.5 Unit 5: Global Water

The final unit for the STEM English course focuses on global water distribution. This topic was selected because it represents an important and easy-to-understand environmental topic that the students are unlikely to have learned in detail. In addition, the final topic was designed to have the students think more critically about an environmental topic.

a. The Reading Text

The reading text for the global water topic focused on the distribution of water on Earth, in particular, the split between saline water and fresh water. The text describes how most available freshwater for human consumption is underground, commonly known as groundwater. The text also describes the relationship between groundwater and surface water and some threats that we should be aware of to protect freshwater resources.

b. The Hands-On Experiment

The hands-on experiment for the global water text was somewhat more passive than the experiments described in the previous sections. For the experiment, the students were required to estimate their daily water budget, i.e. how much water they use daily. The experiment required the students to not only think about their direct water use (i.e. water used in showers, washing hands, laundry etc.) but also consider their indirect water use, i.e. the water used in the production of food.

For the direct water use estimate, students were required to calculate the volumetric flow rate of water from their shower and sink in their homes. Knowing the volumetric flow rate, they could then estimate the length of time they spent with the water running and, therefore, calculate the volume of water used. For the indirect component of the water budget, students were provided with a simple MS Excel spreadsheet that converted the mass of foodstuffs into the volume of water used to produce the food. Students recorded a simple food diary of the basic food they ate in a day and estimated the mass of the food. The food mass was then entered into the Excel spreadsheet, and an estimate of the water volume associated with the food production was calculated.

c. Oral Presentation

The oral presentation content for this unit provided the students with an opportunity to reflect upon their estimated water budgets and consider ways in which they might reduce their water budget.

2.3 Course Implementation

The STEM English course has been offered in the Fall semester for undergraduate students since 2019. Course enrollment each year ranges between 80 to 90 students.

2.4 Student Surveys

During the Fall 2021 semester, a short survey was conducted to assess the student's perceived development of learned vocabulary for Units 2-5. Specifically, to what degree did the students believe that the reading text, hands-on experiment, and presentation activities aided them in developing their STEM English vocabulary? Following the completion of Unit 2, 3, 4 and 5, the students were asked to rate on a 6-point Likert scale how much each activity had helped them develop their vocabulary skills. The survey questions were given in both Japanese and English. The results from the survey were compared against each other, and t-tests were applied to investigate whether there was a statistical difference between the results. The survey questions included

Q1) The reading materials on (UNIT THEME) helped improve my vocabulary skills.

Q2) Planning and conducting the experiment on (UNIT THEME) helped improve my vocabulary skills.

Q3) The presentation activity on (UNIT THEME) helped improve my vocabulary skills.

3. Results and Discussion

The following section provides a summary of the data collected on the STEM English course. The data presented in this section includes an analysis of the readability of the texts created for this course compared to the readability of text from the textbook used in the ET5 course. In addition, survey data on students' perceived improvements in vocabulary skills will also be presented.

3.1 Evaluation of Reading Texts

The texts were intended to provide the students with slightly challenging material to read, yet still be comparable to reading materials they would have encountered in English Topics 5 classes. The Flesch reading ease and Flesch-Kincaid reading grades were calculated for the text described in this study. Both of these scores indicate how easy a text is to read. The reading ease score ranges

from 1 to 100, where 100 is very easy to read, and 1 is very difficult to read. The reading grade refers to the grade level in the US education system.

Table 2 compares the reading ease and reading grade of the text described in this paper and eight reading passages (Unit 1A to Unit 4B) taken from the ET5 textbook (Reading Explorer 2¹⁰). These results indicate that the texts created for the STEM English course were comparable in terms of reading ease and reading grade to reading materials students would have encountered in the ET5 course. The reading grades for the STEM English texts were, on average, slightly higher. However, this is considered an appropriate difference as it provides the students with slightly more challenging reading materials in line with their advancing English skills.

Table 2 Reading ease and reading grade score for the STEM English texts.

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Reading Explorer
Flesch reading ease	54	56	71	62	69	50-86
Flesch-Kincaid reading grade	8	10	10	10	8	5-9

3.2 The Usefulness of Course Activities on Strengthening English Vocabulary

The survey questions were administered to all students enrolled in the course during Fall 2021. However, as it was desirable to analyze the data using t-tests, only the data from students who were present for all class activities is presented here. A total of 47 students were consistently present for all class activities and surveys. The mean and standard deviation (stdev) for the three survey questions are summarized in Table 3. It is clear that the majority of student's responses were positive to all activities.

Table 3 Descriptive statistics for the survey questions administered after the completion of Units 2-5

Course Unit		Q1 The reading materials on (UNIT THEME) helped improve my vocabulary skills.	Q2. Planning and conducting the experiment on (UNIT THEME) helped improve my vocabulary skills.	Q3. The presentation activity on (UNIT THEME) helped improve my vocabulary skills.
Unit 2	Mean	5.07	4.56	4.8
	stdev	0.9	1.0	0.96
Unit 3	Mean	4.94	4.52	4.92
	stdev	1.01	1.1	1.1
Unit 4	Mean	5.07	4.62	5.11
	stdev	0.93	1.1	0.83
Unit 5	Mean	5.08	4.91	5.02
	stdev	0.76	1.1	0.98

With respect to how beneficial the students perceived each task within each unit, t-tests were used to compare the students' perceived development of their vocabulary skills for each activity for the four different topics. The first unit introduced (Unit 1 – STEM Fundamentals) was not used as part

of this evaluation as this unit did not include an experiment and presentation component. Table 4 shows a summary of the t-test results when comparing student responses. The results compare the students' responses to text versus experiment activities, text versus presentation activities and experiment versus presentation activities.

Table 4 T-test p values from student survey responses

Course Unit	Text vs Experiment	Text vs Presentation	Experiment vs Presentation
	Vocabulary Skills		
Unit 2	0.0005	0.046	0.022
Unit 3	0.01	0.86	0.019
Unit 4	0.004	0.72	0.0006
Unit 5	0.21	0.62	0.46

When comparing the reading comprehension activities with the hands-on experiment activities, the students did perceive benefits with respect to improvement in the English vocabulary ($p = 0.01 - 0.0005$, $\alpha = 0.05$). This is expected, as the reading comprehension activity was the first opportunity to introduce new vocabulary. Interestingly, the topic related to water resources did not follow this trend. This is possibly because it was the last topic introduced during the 15-week semester, and much of the vocabulary had already been covered in previous sections or because the vocabulary was perceived to be too specialized by the students and, therefore, did not contribute to the sense of useful vocabulary. There were also significant differences with respect to perceived improvements in vocabulary skills between the experiment and presentation activities ($p = 0.022 - 0.0006$, $\alpha = 0.05$). During the experiment lessons, the students were rereading the same vocabulary. However, during the presentation lessons, students were required to use the target vocabulary meaningfully. This may have reinforced the need for the students to understand and use the target vocabulary accurately. Interestingly, with the exception of Unit 2, there is no statistical difference in student's perceived improvements in vocabulary skills when comparing the reading comprehension activity and the presentation activity. This potentially indicated that reading comprehension and presentation activities alone may not be sufficient to reinforce vocabulary development skills in the STEM English classroom. It could, therefore, be inferred that the hands-on experiments conducted in the STEM English course do play an important role in improving students' perceived vocabulary skills.

4. Conclusion

The objective of this report was to introduce the content and structure of the STEM English course at KIT. The teaching materials developed for this course provide students with authentic science-based content, including hands-on in-class experiments and oral presentations. The preliminary survey results on students' perceived benefits of the lesson materials on the development of their vocabulary skills are encouraging. The results suggest that the hands-on experiment component of the course materials is beneficial in aiding vocabulary development. These results are promising

and should be explored further to include both quantitative and qualitative assessments of students' perceived L2 skill development.

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